



## B physics at LEP: selected topics

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**B PHYSICS AT LEP  
SELECTED TOPICS**

**Talby M.**

**Invited talk at the XVIII International Workshop on High Energy  
Physics and Field Theory, Protvino-Russia, 24-30 June 1995**

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# ***B* physics at LEP**

## **selected topics**

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### **Abstract**

Four selected topics on *B* Physics at LEP are reviewed. These topics cover  $Z \rightarrow b\bar{b}$  partial width,  $b$  hadron lifetimes,  $B^0 - \bar{B}^0$  mixing and the *CKM* matrix element  $V_{cb}$ . The latest results from the four LEP experiments are presented and discussed.

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# 1 Introduction

Since it started in summer 1989 LEP has provided, in addition to the very precise tests of the standard model of electroweak interactions, a set of remarkably new results in  $B$  physics. The four LEP experiments, ALEPH, DELPHI, L3 and OPAL have collected a total of 12 million hadronic  $Z^0$  by the end of 1994. This impressive number of events has led to an interesting and exciting developpement in  $B$  physics at LEP. Four selected topics in this field are presented in this contribution. They cover  $Z \rightarrow b\bar{b}$  partial width,  $b$  hadron lifetimes,  $B^0 - \bar{B}^0$  mixing and the  $CKM$  matrix element  $V_{cb}$ .

In this article I have used updated values.

## 2 The measurement of $R_b = \frac{\Gamma(Z^0 \rightarrow b\bar{b})}{\Gamma(Z^0 \rightarrow \text{hadrons})}$

In the standard model of electroweak interactions the  $Z \rightarrow b\bar{b}$  width receives a specific vertex correction involving the top quark mass and is independent of the Higgs mass. This correction is suppressed for the other quark final states. Therefore the measurement of the ratio  $R_b = \Gamma(Z^0 \rightarrow b\bar{b})/\Gamma(Z^0 \rightarrow \text{hadrons})$  is of particular interest since it is an observable sensitive to the top quark mass.

Experimentally the procedure to measure  $R_b$  is simple in principle, one counts, around the  $Z$  peak, the number of  $e^+e^- \rightarrow \text{hadrons}$  events, tags  $e^+e^- \rightarrow b\bar{b}$  events by some means with known efficiency and extracts  $R_b$ .

Three methods have been used at LEP to measure  $R_b$ :

- Inclusive semileptonic  $b$  hadrons decays where  $b\bar{b}$  events are selected using the  $p$  and  $p_\perp$  distributions of the lepton.
- Event shape method where  $b\bar{b}$  events are selected based on their specific spherical decay shape using kinematic variables with the help of a neural network.
- lifetime tagging exploits the relatively long  $b$  hadron decay length (few millimeters) compared to the other hadrons, to select  $b\bar{b}$  events. This task which consists of tagging displaced vertices is facilitated by the use of a micro vertex detector. This method is the most powerful among the three, it can achieve  $b\bar{b}$  purity of 90% for 40% efficiency which is to be compared to 10% efficiency for the same purity using the inclusive semileptonic tag.

In these analyses the knowledge of the  $b\bar{b}$  tagging efficiency is an important issue. To have a better control on this important parameter, a double tagging technique, where the two hemispheres of a selected event are used separately, is applied. With this technique systematic errors associated with uncertainties in  $b$  hadron production and decay are eliminated but on the other hand one needs to know the correlations

Experiment	method	$R_b (R_c = 0.171)$
ALEPH [1]	lepton fit	$0.2190 \pm 0.0060(\text{stat}) \pm 0.0050(\text{syst})$
ALEPH [2]	event shape	$0.2280 \pm 0.0050(\text{stat}) \pm 0.0050(\text{syst})$
ALEPH [3]	lifetime tag	$0.2192 \pm 0.0022(\text{stat}) \pm 0.0026(\text{syst})$
DELPHI [4]	lifetime + lepton	$0.2231 \pm 0.0029(\text{stat}) \pm 0.0035(\text{syst})$
DELPHI [4]	multivariate	$0.2186 \pm 0.0032(\text{stat}) \pm 0.0022(\text{syst})$
DELPHI [4]	lifetime tagg	$0.2216 \pm 0.0017(\text{stat}) \pm 0.0027(\text{syst})$
L3 [5]	lepton fit	$0.2187 \pm 0.0081(\text{stat}) \pm 0.0080(\text{syst})$
L3 [6]	event shape	$0.2220 \pm 0.0030(\text{stat}) \pm 0.0070(\text{syst})$
OPAL [7]	lepton fit	$0.2220 \pm 0.0110(\text{stat}) \pm 0.0070(\text{syst})$
OPAL [8]	lifetime tag	$0.2171 \pm 0.0021(\text{stat}) \pm 0.0021(\text{syst})$
LEP average	all	$0.2198 \pm 0.0016$
Standard Model		$0.2157 (m_t = 179 \text{ GeV}/c^2)$

Table 1: Summary of the  $R_b$  measurements at LEP

between the two hemispheres. Apart from the efficiency, another important parameter to keep under control is the background level (mainly charm).

The measured value of  $R_b$  depends on the value of  $R_c(\Gamma(Z^0 \rightarrow c\bar{c})/\Gamma(Z^0 \rightarrow \text{hadrons}))$  and the two are highly correlated. The measurements of  $R_b$  from the 4 LEP experiments (assuming the standard model value for  $R_c = 0.171$ ) are summarized in table 1. The average value of  $R_b$  is  $2.5 \sigma$  above the value predicted by the standard model for a top quark mass of  $m_t = 179 \text{ GeV}/c^2$ . This is an important result since it represents the only observed deviation from the standard model. To have more confidence on this result,  $R_b$  needs to be measured with a much better accuracy. Since half the error on  $R_b$  is systematic, more work is needed to have a better control of the systematics.

### 3 Measurements of $b$ hadron lifetimes

In the spectator model [9] all hadrons with a particular heavy quark  $Q$  are predicted to have equal lifetime. This simple picture is based on the assumption that heavy hadron decays are governed by the decay of the heavy quark independently of the light constituent quark(s). Experimental results in the charm sector [10] ( $\tau_{D^+} \simeq 2.6 \tau_{D^0} \simeq 2.2 \tau_{D_s^+} \simeq 5 \tau_{\Lambda_c^+}$ ) show important deviations from this picture. These deviations are understood to arise from non-spectator decays such as W-exchange, W-annihilations or destructive interference between colour-suppressed and colour-allowed decay amplitudes giving the same final state. Quantitatively these corrections induce differences between the total decay widths of the order  $1/m_Q^2$ . In the beauty sector due to larger  $b$  quark mass non-spectator effects should be smaller

than in the charm sector. As for charmed hadrons the predicted hierarchy between  $b$  hadron lifetimes is:  $\tau_{B^+} > \tau_{B_d^0} \approx \tau_{B_s^0} > \tau_{\Lambda_b}$ . More precisely the following ratios are predicted [11]:

$$\begin{aligned}\tau_{B^+}/\tau_{B_d^0} &= 1.0 + 0.05\left(\frac{f_B}{200\text{MeV}}\right)^2 \\ \tau_{B_s^0}/\tau_{B_d^0} &= 1.0 \\ \tau_{\Lambda_b}/\tau_{B_d^0} &\approx 0.9\end{aligned}\tag{1}$$

An experimental verification of these theoretical predictions is important as it tests the significance of non-perturbative corrections in  $b$  hadron decays.

### 3.1 Experimental techniques

Two main techniques are used to measure the  $b$  hadron lifetimes at LEP :

- The impact parameter method (developped in the early experiments at PEP and PETRA as an alternative to poor  $b$  vertexing precision) is used mainly for inclusive  $b$  hadron lifetime measurements and in cases where the  $b$  hadron decay length cannot be reconstructed. For semileptonic  $b$  hadron decays the impact parameter of the lepton with respect to the primary vertex (interaction point) is directly related to the proper decay time of the  $b$  hadron.
- The decay length method is mainly used for exclusive  $b$  hadrons lifetime measurements. In this method the proper time of the  $b$  hadron decay is given by:

$$t_b = \frac{l_b m_b}{P_b}\tag{2}$$

Where  $l_b$ ,  $m_b$  and  $P_b$  are the reconstructed  $b$  hadron decay length, mass and momentum respectively. The  $b$  hadron decay length is measured with a precision of  $300 \mu m$  using the high resolution vertex detector. The mass and the momentum of the  $b$  hadron are determined from its reconstructed decay products and with the help of missing neutrino energy in the case of semileptonic  $b$  hadron decays. The typical resolution on the proper time  $t_b$  with this method is 10-20 %.

### 3.2 Inclusive $b$ hadron lifetime

The most accurate measurements of the average  $b$  hadron lifetime at LEP were performed using :

Experiment	method	$\langle\tau_b\rangle$ (ps)
ALEPH [12]	$e\mu$	$1.533 \pm 0.013(\text{stat}) \pm 0.022(\text{syst})$
DELPHI [13]	$e\mu$	$1.542 \pm 0.021(\text{stat}) \pm 0.045(\text{syst})$
DELPHI [16]	inclu. had.	$1.600 \pm 0.010(\text{stat}) \pm 0.028(\text{syst})$
L3 [14]	$e\mu$	$1.535 \pm 0.035(\text{stat}) \pm 0.028(\text{syst})$
OPAL [15]	$e\mu$	$1.523 \pm 0.034(\text{stat}) \pm 0.038(\text{syst})$
LEP average (1)	$e\mu$	$1.533 \pm 0.019$
LEP average (2)	all	$1.550 \pm 0.016$

Table 2: Summary of the inclusive  $b$  hadron lifetime measurements at LEP

- Impact parameter of high  $p_T$  leptons from semileptonic  $b$  hadron decays.
- Vertex topology in hadronic  $b$  decays.

The impact parameter method [12] [13] [14] [15], uses the Monte Carlo to estimate the background fraction and composition. The average  $b$  hadron lifetime is extracted by an unbinned maximum likelihood fit to the impact parameter distribution of the lepton candidates.

The second method [16] uses displaced multiprong vertices, in a  $b$  hadron enriched sample, to reconstruct  $b$  hadron decay point. In this method the average  $b$  hadron lifetime is extracted from the reconstructed decay length distribution using a physics function, estimated from the Monte Carlo, which relates the  $b$  hadron decay length to its proper decay time.

The measurements of the average  $b$  hadron lifetime from the 4 LEP experiments and their average are summarized in table 2. The lifetime measured by DELPHI with the second method is about  $2\sigma$  higher than the lifetime measured from inclusive  $b$  hadron semileptonic decays. This difference is not yet understood. Systematics in these measurements may have been underestimated.

### 3.3 Exclusive $b$ hadron lifetimes

#### 3.3.1 $B^+$ and $B_d^0$ lifetimes

Three methods have been used at LEP to measure the  $B^+$  and  $B_d^0$  lifetimes.

- Fully reconstructed  $B^+$  and  $B_d^0$  decays.
- Partially reconstructed  $B \rightarrow \bar{D}^{(*)}\ell\nu X$  decays.
- Topological secondary vertex reconstruction.

**a) Fully reconstructed  $B^+$  and  $B_d^0$  decays:**

ALEPH has reconstructed a total of 94  $B^+$  and 121  $B_d^0$  events in different decay channels [17]:

- $B^+ \rightarrow \bar{D}^0 \pi^+, \bar{D}^0 a_1^+, (J/\psi, \psi(2s)) K^+, (J/\psi, \psi(2s)) K^{*+}$
- $B^0 \rightarrow D^- \pi^+, D^{*-} \pi^+, D^{*-} \rho^+, D^{*-} a_1^+, (J/\psi, \psi(2s)) K_s^0, (J/\psi, \psi(2s)) K^{*0}$

This method has two advantages: the reconstructed  $B$  events are almost background free and their proper times are measured with a very good accuracy. Consequently the  $B^+$  and  $B_d^0$  lifetime measurements have a low systematic uncertainty but due to the limited number of reconstructed events the statistical accuracy is limited.

**b) Partially reconstructed  $B \rightarrow \bar{D}^{(*)} \ell \nu X$  decays:**

In this method  $B^+$  and  $B_d^0$  are identified using  $D^{(*)}$ -lepton correlations. Events with  $D^{(*)-} \ell^+$  are dominantly from  $B_d^0$  decay and events with  $\bar{D}^0 \ell^+$  (excluding  $D^{*-} \rightarrow \bar{D}^0 \pi^-$ ) are dominantly from  $B^+$  decay. This simple discrimination criterion between  $B^+$  and  $B_d^0$  gets complicated by higher excited charm states contributions namely  $B \rightarrow D^{**} \ell \nu$ ,  $D^{**} \rightarrow D^{(*)} \pi$  which accounts for about 30% of the semileptonic  $B$  decays. In these decays  $D^{(*)-} \ell^+$  receive contributions from  $B^+$  and  $\bar{D}^0 \ell^+$  from  $B_d^0$ . Kinematical and topological rejection criteria are used to reduce this misassociation and corrections are applied to take into account the remaining contamination. The  $B^+$  and  $B_d^0$  lifetimes are extracted from their proper time distribution reconstructed as explained in section 3.1. This method has been used by ALEPH [17], DELPHI [18] and OPAL [19] collaborations. For the measurement of  $B_d^0$  lifetime ALEPH has also used partially reconstructed  $B_d^0 \rightarrow \pi_B^+ X D^{*-}$ ;  $D^{*-} \rightarrow \pi_D^- \bar{D}^0$  decays where only  $\pi_B^+ \pi_D^-$  pairs were reconstructed.

**c) Topological secondary vertex reconstruction:**

Inclusive secondary vertex reconstruction similar to the average  $b$  hadron lifetime measurement has been used by DELPHI [20] to measure  $B^+$  and  $B_d^0$  lifetimes. The separation between  $B^+$  and neutral  $b$  hadron states is based on the net charge of the tracks at the decay vertex. This method benefits from large statistic and systematic uncertainties due to incorrect assignment of tracks to the decay vertex seem to be well controlled. This method has provided the most accurate measurement of the  $B^+$  lifetime. The  $B^0$  lifetime is extracted from the selected  $b$  hadron component using independent measurements of the  $\Lambda_b$  and  $B_s^0$  fractions and lifetimes.

The measurements of the  $B_d^0$  and  $B^\pm$  lifetimes, are summarized in tables 3 and 4.

**3.3.2  $B_s^0$  lifetime**

The  $B_s^0$  lifetime has been measured at LEP using partial reconstruction of the semileptonic decay  $B_s^0 \rightarrow D_s^+ \ell^- \bar{\nu}$  and the hadronic decay  $B_s^0 \rightarrow D_s^+ \text{hadron}$  [21] [22] [23] [24]. The  $D_s^+$  candidates were reconstructed in  $\phi \pi^+$  and  $\bar{K}^{*0} K^+$  decay



Experiment	method	$\tau_{B_d^0}$ (ps)
ALEPH [17]	full. recons.	$1.25^{+0.15}_{-0.13}(\text{stat}) \pm 0.05(\text{syst})$ *
ALEPH [17]	$D^*\ell$	$1.61 \pm 0.07(\text{stat}) \pm 0.04(\text{syst})$ *
ALEPH [17]	$\pi_B^+\pi_{D^*}^-$	$1.49^{+0.17}_{-0.15}(\text{stat})^{+0.08}_{-0.06}(\text{syst})$ *
DELPHI [20]	inclu. vertex recons.	$1.63 \pm 0.14(\text{stat}) \pm 0.13(\text{syst})$
DELPHI [18]	$D^*\ell$	$1.61^{+0.14}_{-0.13}(\text{stat}) \pm 0.08(\text{syst})$
OPAL [19]	$D^*\ell$	$1.53 \pm 0.12(\text{stat}) \pm 0.08(\text{syst})$
LEP average	all	$1.555 \pm 0.059$

Table 3: Summary of the  $B_d^0$  lifetime measurements at LEP. Values quoted with a \* are preliminary results

Experiment	method	$\tau_{B^+}$ (ps)
ALEPH [17]	full. recons.	$1.58^{+0.21}_{-0.18}(\text{stat}) \pm 0.04(\text{syst})$ *
ALEPH [17]	$D^*\ell$	$1.58 \pm 0.09(\text{stat}) \pm 0.04(\text{syst})$ *
DELPHI [20]	inclu. vertex recons.	$1.72 \pm 0.08(\text{stat}) \pm 0.06(\text{syst})$
DELPHI [18]	$D^*\ell$	$1.61 \pm 0.16(\text{stat}) \pm 0.12(\text{syst})$
OPAL [19]	$D^*\ell$	$1.52 \pm 0.14(\text{stat}) \pm 0.09(\text{syst})$
LEP average	all	$1.631 \pm 0.060$

Table 4: Summary of the  $B^+$  lifetime measurements at LEP. Values quoted with a \* are preliminary results

channels. Candidates  $B_s^0$  are identified using  $D_s^+\ell^-$  and  $D_s^+ \text{hadron}^-$  charge correlation. Apart from these two channels, DELPHI has used two other complementary methods ( $\phi\ell^\pm$  and inclusive  $D_s^+$ ) to measure the  $B_s^0$  lifetime. In hadronic and inclusive channels the systematic errors are large compared to the semileptonic channel due mainly to the estimation of the background.

The measurements of the  $B_s^0$  lifetime with these different methods are summarized in table 5.

### 3.3.3 $b$ baryon lifetime

For  $\Lambda_b$ , mainly two methods have been used by the LEP collaborations to select  $\Lambda_b$  candidates. The two methods search for semileptonic  $\Lambda_b$  decay through the charge correlation between a lepton and a fully reconstructed baryon  $\Lambda$  or  $\Lambda_c$  [25] [26] [27] [28] namely  $\Lambda\ell^-$  or  $\Lambda_c^+\ell^-$ . These right-sign combinations are expected to be dominantly from  $\Lambda_b \rightarrow \Lambda_c^+\ell^-\bar{\nu}X$ . A small fraction of  $\Lambda\ell^-$  combinations is expected to come also from  $\Xi_b$  semileptonic decays. Assuming that  $\Lambda_b$  is the dominant source of  $b$  baryons at the Z resonance  $\Lambda\ell^-$  combinations can be considered as mainly sensitive to  $\Lambda_b$  semileptonic decays.

Experiment	method	$\tau_{B_s^0}$ (ps)
ALEPH [21]	$D_s$ hadron	$1.61^{+0.30}_{-0.29}(\text{stat})^{+0.18}_{-0.16}(\text{syst})$
ALEPH [22]	$D_s \ell$	$1.64^{+0.16}_{-0.14}(\text{stat}) \pm 0.04(\text{syst})$
DELPHI [23]	$D_s$ hadron	$1.57^{+0.45}_{-0.37}(\text{stat})^{+0.15}_{-0.14}(\text{syst})$
DELPHI [23]	$D_s \ell$	$1.54^{+0.31}_{-0.27}(\text{stat}) \pm 0.06(\text{syst})$
DELPHI [23]	$D_s$ inclu.	$1.61^{+0.34}_{-0.29}(\text{stat})^{+0.18}_{-0.13}(\text{syst})$
DELPHI [23]	$\phi \ell$	$1.45^{+0.20}_{-0.23}(\text{stat})^{+0.32}_{-0.16}(\text{syst})$
OPAL [24]	$D_s \ell$	$1.54^{+0.25}_{-0.21}(\text{stat}) \pm 0.06(\text{syst})$
LEP average	all	$1.591 \pm 0.106$

Table 5: Summary of the  $B_s^0$  lifetime measurements at LEP.

Experiment	method	$\tau_{\Lambda_b}$ (ps)
ALEPH [25]	$\Lambda_c^+ \ell^-$	$1.24^{+0.15}_{-0.14}(\text{stat}) \pm 0.05(\text{syst})$ *
ALEPH [25]	$\Lambda \ell^-$	$1.21 \pm 0.09(\text{stat}) \pm 0.07(\text{syst})$ *
DELPHI [26]	$\Lambda_c^+ \ell^-$	$1.26^{+0.26}_{-0.22}(\text{stat})^{+0.03}_{-0.05}(\text{syst})$
DELPHI [26]	$\Lambda \ell^-$	$1.10^{+0.16}_{-0.14}(\text{stat})^{+0.05}_{-0.08}(\text{syst})$
OPAL [27]	$\Lambda_c^+ \ell^-$	$1.14^{+0.22}_{-0.19}(\text{stat}) \pm 0.07(\text{syst})$
OPAL [28]	$\Lambda \ell^-$	$1.16 \pm 0.11(\text{stat}) \pm 0.06(\text{syst})$
LEP average	all	$1.184 \pm 0.065$

Table 6: Summary of the  $\Lambda_b$  lifetime measurements at LEP. Values quoted with a \* are preliminary results

The two lifetime measurement techniques discussed in 3.1 were used to determine the  $\Lambda_b$  lifetime. For  $\Lambda_c^+ \ell^-$  combinations the decay length method has been used and for  $\Lambda \ell^-$  combinations ALEPH and OPAL used the impact parameter method while DELPHI requiring an additional pion used the decay length method.

The  $\Lambda_b$  lifetime measurements are summarized in table 6.

### 3.4 conclusion on $b$ hadron lifetimes

A summary of the exclusive  $b$  hadron lifetimes is presented in Figure 1 with a comparison to the inclusive measurement. As can be seen the pattern of measured lifetimes  $\tau_{B^+} > \tau_{B_d^0} \approx \tau_{B_s^0} > \tau_{\Lambda_b}$  follows the theoretical predictions outlined in section 3 however, the ratio of  $\Lambda_b$  and  $B_d^0$  lifetimes which is  $0.761 \pm 0.051$  is  $2.7 \sigma$  smaller than the theoretical estimation of 0.9 [11]. This discrepancy with the theoretical prediction remains to be understood. Assuming the relative production of  $b$  hadrons  $B^+$ ,  $B_d^0$ ,  $B_s^0$ ,  $\Lambda_b$  at the Z resonance to be : 0.39 : 0.39 : 0.12 : 0.10, the average  $b$  hadrons lifetime calculated from exclusive measurements is  $1.552 \pm 0.036$  ps, in good

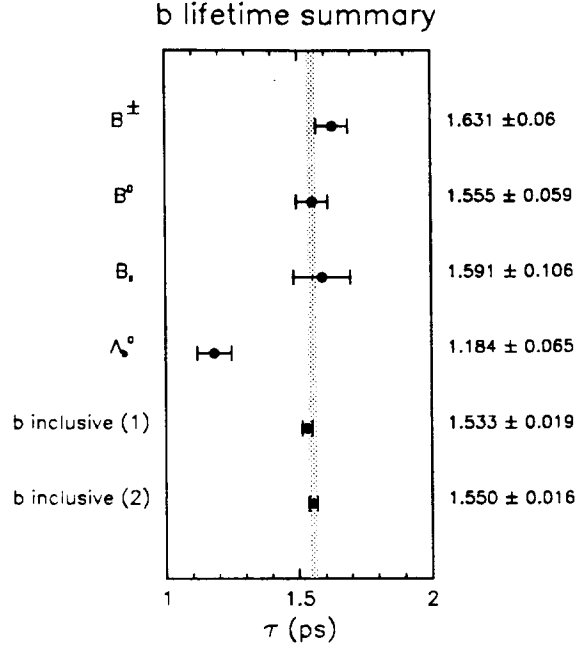


Figure 1: Summary of the exclusive  $b$  hadron lifetimes measurements at LEP with a comparison to the inclusive measurement.

agreement with inclusive  $b$  hadron lifetime value  $1.533 \pm 0.019$  ps (or  $1.550 \pm 0.016$  ps).

#### 4 $B^0 - \bar{B}^0$ mixing

As in the  $K^0 \bar{K}^0$  system, neutral  $B$  mesons with mass eigenstates  $B_1$  and  $B_2$  are linear combinations of flavour eigenstates  $B^0$  and  $\bar{B}^0$ . Neglecting  $CP$  violation one obtains:

$$B_1 = \frac{1}{\sqrt{2}}(B^0 + \bar{B}^0) \quad (3)$$

$$B_2 = \frac{1}{\sqrt{2}}(B^0 - \bar{B}^0)$$

This feature leads to the phenomena of  $B^0 - \bar{B}^0$  mixing. The probability that the state, initially produced as  $B^0$  mixes into  $\bar{B}^0$  at time  $t$  is (neglecting  $CP$  violation) given by:

$$P(B^0 \rightarrow \bar{B}^0, t) = e^{-\Gamma t} [1 - \cos(\Delta m t)] \quad (4)$$

where  $\Gamma$  is the decay width of  $B_1$  and  $B_2$  states and  $\Delta m$  their mass difference. This oscillatory behaviour, with frequency  $\Delta m$ , of the  $B^0 - \bar{B}^0$  mixing probability

proceeds via second order weak interaction as described by the Box-diagrams shown in figure 2.

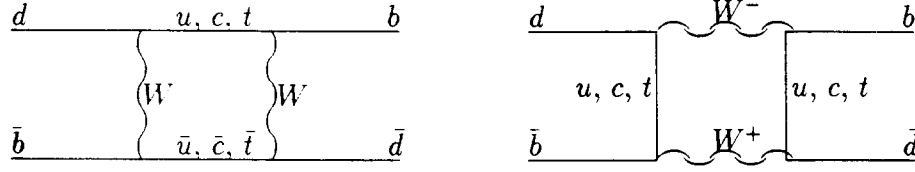


Figure 2: Box-diagrams: oscillation between  $B_d^0$  et  $\bar{B}_d^0$  states.

The integrated probability  $\chi$  that a  $B^0$  mixes to  $\bar{B}^0$  is given by:

$$\chi = \frac{1}{2} \frac{(\Delta m / \Gamma)^2}{1 + (\Delta m / \Gamma)^2} \quad (5)$$

The first evidence of  $B^0 - \bar{B}^0$  mixing was found by UA1 [29]. This experiment could not distinguish between  $B_s^0$  and  $B_d^0$  and has measured an average mixing  $\bar{\chi} = f_s \chi_s + f_d \chi_d$ , where  $\chi_s$  and  $\chi_d$  are respectively the time integrated probability of  $B_s^0$  and  $B_d^0$ ,  $f_s$  and  $f_d$  are their relative abundance. Evidence of  $B_d^0 - \bar{B}_d^0$  mixing was first reported by ARGUS [30] and confirmed by CLEO [31].

The theoretical prediction of the oscillation frequencies  $\Delta m_d$  for  $B_d^0$  and  $\Delta m_s$  for  $B_s^0$  are derived from calculations of the Box-diagrams contributions where the top quark exchange dominates:

$$\Delta m_{d,s} = \frac{G_F^2}{6\pi^2} m_{B_{d,s}} m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) \eta B_{B_{d,s}} f_{B_{d,s}}^2 |V_{tb}^* V_{td,s}|^2 \quad (6)$$

$G_F$  is the Fermi coupling constant,  $m_t$  is the top quark mass,  $F$  is a function which depends on  $m_t$  and  $m_W$ ,  $\eta$  is a  $QCD$  correction factor,  $B_{B_d}$  is the so called bag-factor and  $f_{B_d}$  the  $B_d^0$  decay constant. The largest theoretical uncertainty on  $\Delta m_{d,s}$  comes from the product  $B_{B_{d,s}} f_{B_{d,s}}^2$ .

The dependence on the top quark mass drops out in the ratio  $\Delta m_s / \Delta m_d$ :

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s} \eta_{B_s} B_{B_s} f_{B_s}^2}{m_{B_d} \eta_{B_d} B_{B_d} f_{B_d}^2} \left| \frac{V_{ts}}{V_{td}} \right|^2 \quad (7)$$

From the allowed range of  $|V_{ts}/V_{td}|$  within the  $CKM$  matrix, a recent theoretical estimation [44] shows that  $\Delta m_s / \Delta m_d$  lies at 95% *C.L.* within:

$$10.5 \left( \frac{\xi}{1.16} \right)^2 \leq \frac{\Delta m_s}{\Delta m_d} \leq 77.7 \left( \frac{\xi}{1.16} \right)^2 \quad (8)$$

where  $\xi = (f_{B_s} \sqrt{B_{B_s}}) / (f_{B_d} \sqrt{B_{B_d}}) = 1.16 \pm 0.1$ .

This large allowed range which reflects the poor knowledge of  $|V_{ts}/V_{td}|$ , shows also that for  $B_s^0 - \bar{B}_s^0$  the oscillation frequency is at least 10 times higher than for  $B_d^0 - \bar{B}_d^0$ .

Experiment	method	$\bar{\chi}$ in %
ALEPH [33]	dilepton tagging	$10.6 \pm 0.7(\text{stat}) \pm 0.9(\text{syst})$ *
DELPHI [34]	dilepton tagging	$15.4 \pm 2.0(\text{stat}) \pm 1.5(\text{syst})$
L3 [35]	dilepton tagging	$12.3 \pm 1.2(\text{stat}) \pm 0.8(\text{syst})$
OPAL [36]	dilepton tagging	$14.4 \pm 2.2(\text{stat}) \pm 0.7(\text{syst})$
LEP average		$11.5 \pm 0.6$

Table 7: Summary of the time integrated  $B^0 - \bar{B}^0$  mixing. The value quoted with a \* is a preliminary result.

#### 4.1 Time integrated mixing

The measurement of  $B^0 - \bar{B}^0$  mixing requires identification of the particle/antiparticle state both at its production and at its decay. The experimental technique commonly used to measure the time integrated mixing  $\chi$  is the dilepton tag method. In  $b\bar{b}$  events where both  $b$  hadrons decay semileptonically, like-sign lepton pair is a signature of mixing. The fraction of the like-sign (mixed) events is given by:

$$R = \frac{N_{\pm\pm}}{N_{\pm\pm} + N_{\pm\mp}} \quad (9)$$

The main background affecting  $R$  comes from cascade decay  $b \rightarrow c \rightarrow \ell$ .

At the  $\Upsilon(4s)$   $\chi_d$  is related to  $R$  by  $\chi_d = (1 + \lambda)R$ , where  $\lambda = 1.13 \pm 0.19$  is a correction for the contribution of  $B^+ B^-$  events to the like-sign fraction. The average value of  $\chi_d$  measured by experiments running at the  $\Upsilon(4s)$  is [32]  $\chi_d = 0.168 \pm 0.024$ . This corresponds to  $\Delta m_d / \Gamma_d = 0.711 \pm 0.077$  which, using the LEP average value  $\tau_{B^0} = 1.555 \pm 0.059$  ps corresponds to  $\Delta m_d = 0.457 \pm 0.049 \pm 0.018$  ps<sup>-1</sup>.

At LEP both  $B_s^0$  and  $B_d^0$  are produced, consequently the measured time integrated mixing is  $\bar{\chi} = f_s \chi_s + f_d \chi_d$ . Since  $b\bar{b}$  pairs are produced incoherently  $\bar{\chi}$  is related to  $R$  by  $R \approx 2\bar{\chi}(1 - \bar{\chi})$ . The measurement of  $\bar{\chi}$  at LEP has been performed mainly by the dilepton method. ALEPH and DELPHI have also used the jet charge method but this techniques leads to a slightly different sensitivity to  $B_s^0$  and  $B_d^0$ .

The measurements of  $\bar{\chi}$  from the LEP experiments are summarized in table 7. The LEP average value is  $\bar{\chi} = 0.115 \pm 0.006$ . Assuming  $f_s = 0.12$  and  $f_d = 0.39$ , this value gives  $\chi_s > 0.30$  at 95% *C.L.*, which corresponds to  $\Delta m_s / \Gamma_s > 1.22$  at 95% *C.L.* and using  $\Delta m_d = 0.457 \pm 0.049 \pm 0.018$  ps<sup>-1</sup> and  $\tau_{B_s} = 1.591 \pm 0.106$  ps translates to  $\Delta m_s / \Delta m_d > 1.7(\pm 0.2)$  at 95% *C.L.* which is much smaller than the expected lower limit from theoretical prediction. This poor limit reflects the fact that time integrated mixing has no sensitivity to high  $\Delta m_s / \Gamma_s$  since for  $\chi_s = 0.5$ ,  $(\Delta m_s / \Gamma_s) \rightarrow \infty$ . To explore the domain above the expected low theoretical limit of  $\Delta m_s / \Delta m_d$  (see equation 8) one needs time dependent mixing measurements.

## 4.2 Time dependent mixing measurements

The time dependent mixing measurement looks for the characteristic oscillatory behaviour of the mixing which allows the measurement of the frequency  $\Delta m$  directly. The measurement requires a good resolution on the proper time of  $B^0$ , especially for  $B_s^0$  where the oscillation frequency is expected to be high and as in the time integrated mixing, the particle/antiparticle state has to be tagged at both its production and decay times.

The technique used at LEP to measure the time dependent mixing is as follows: The selected  $b\bar{b}$  event candidate is divided into two hemispheres, one hemisphere is used to tag the production flavour and the other to measure the decay flavour and its proper time. The charge correlation between the two hemispheres is used then to tag mixed and unmixed events.

### 4.2.1 $B_d^0 - \bar{B}_d^0$ oscillation

Conditions for observing  $B_d^0 - \bar{B}_d^0$  oscillation are favourable at LEP for two reasons: the relative abundance of  $B_d^0$  among  $b$  hadrons is high ( $f_d \approx 0.39$ ) and its oscillation frequency  $\Delta m_d$  is low (1 oscillation period  $\approx 9 \times \tau_{B_d^0}$ ). The amplitude of the oscillation is however reduced due mainly to proper time resolution, charge mistag and background contamination.

The first measurement of the time dependent  $B_d^0 - \bar{B}_d^0$  mixing was reported by ALEPH [37]. Since then several results have been reported by LEP experiments. They are based mainly on three methods :  $D^{*+}l^-$  (with or without jet-charge), dilepton and lepton and jet-charge. The last two are sensitive to  $B_s^0 - \bar{B}_s^0$  as well, in this case, maximal  $B_s^0$  mixing is assumed for  $\Delta m_d$  measurement. Figure 3 shows the variation of mixed event candidates with the  $B_d^0$  decay proper time measured with the dilepton method by ALEPH.

The latest measurements of  $\Delta m_d$  [38] [39] [40] [41] are summarized in table 8. The LEP average value is  $\Delta m_d = 0.456 \pm 0.020 \text{ ps}^{-1}$  which corresponds to  $\Delta m_d = (3.00 \pm 0.13)10^{-4} \text{ eV}$ .

### 4.2.2 $B_s^0 - \bar{B}_s^0$ oscillation

Compared to  $B_d^0$ , the measurement of  $B_s^0 - \bar{B}_s^0$  oscillation suffers from two limitations: the  $B_s^0$  relative production at LEP is more than three time smaller than  $B_d^0$  ( $f_s \approx 0.12$ ) and its oscillation frequency is much higher. From the expected  $\Delta m_s$  range using  $\Delta m_d$  value and theoretical predictions, one oscillation period  $\approx [0.1, 1] \times \tau_{B_s^0}$ . Further the significance of the oscillation is reduced by the mixed or unmixed mistag rate, background contamination and proper time resolution. These considerations show how difficult a task it is to search for  $B_s^0 - \bar{B}_s^0$  oscillations.

Four methods have been used at LEP to search for  $B_s^0 - \bar{B}_s^0$  oscillations : dilepton, lepton and jet-charge methods mentioned above, lepton-kaon and jet-charge, and  $D_s^- l^+$  correlations. The results of these analyses are summarized in table 9, they all

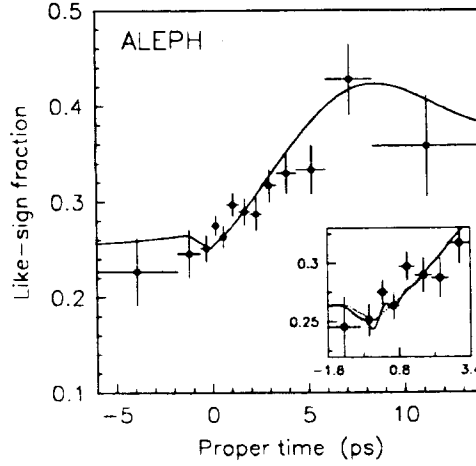


Figure 3: The like-sign fraction as function of reconstructed proper time with  $\Delta m_d$  fit (assuming maximal  $B_s^0$  mixing) superimposed. The insert shows the result of the fit with  $\Delta m_s$  as free parameter.

Experiment	method	$\Delta m_d$ in $\text{ps}^{-1}$
ALEPH [38]	$D^{*+}\ell^{-}, Q_j$	$0.482 \pm 0.044(\text{stat}) \pm 0.025(\text{syst})$ *
ALEPH [38]	$\ell, Q_j$	$0.404 \pm 0.034(\text{stat}) \pm 0.049(\text{syst})$ *
ALEPH [38]	$\ell^+\ell^+$	$0.430 \pm 0.032(\text{stat}) \pm 0.071(\text{syst})$ *
DELPHI [39]	$D^{*+} + D^{*+}\ell^{-}, Q_j$	$0.421 \pm 0.064(\text{stat}) \pm 0.042(\text{syst})$ *
DELPHI [39]	$\ell^+K^+Q_j$	$0.563^{+0.050}_{-0.046}(\text{stat}) \pm 0.058(\text{syst})$ *
DELPHI [39]	$\ell, Q_j$	$0.438^{+0.040}_{-0.051}(\text{stat})^{+0.039}_{-0.057}(\text{syst})$ *
DELPHI [39]	$\ell^+\ell^+$	$0.420 \pm 0.080(\text{stat})^{+0.080}_{-0.070}(\text{syst})$ *
OPAL [40]	$D^{*+}\ell^{-}, Q_j$	$0.539 \pm 0.060(\text{stat}) \pm 0.024(\text{syst})$ *
OPAL [40]	$D^{*+}\ell^{-}$	$0.570 \pm 0.110(\text{stat}) \pm 0.020(\text{syst})$
OPAL [41]	$\ell, Q_j$	$0.439^{+0.030}_{-0.029}(\text{stat})^{+0.020}_{-0.019}(\text{syst})$ *
OPAL [41]	$\ell^+\ell^+$	$0.462^{+0.040}_{-0.053}(\text{stat})^{+0.052}_{-0.035}(\text{syst})$
LEP average	all	$0.456 \pm 0.020$

Table 8: Summary of  $\Delta m_d$  measurements at LEP. Values quoted with a \* are preliminary results

exclude low values of  $\Delta m_s$ . The limit on  $\Delta m_s$  is extracted from the dependence on  $\Delta m_s$  of the Log-likelihood fit of the selected data sample relative to its minimum. The limit is set from the intersection between the data Log-likelihood curve and the expected log-likelihood value (using a fast Monte Carlo simulation), for different  $\Delta m_s$ , for which the  $B_s^0$  mixing has not occurred in 95 % of the sample. For

Experiment	method	$\Delta m_s$ limit (95% C.L.)
ALEPH [45]	lepton-jet	$6.1 \text{ ps}^{-1} (f_s = 0.12)$
ALEPH [38]	dilepton	$5.6 \text{ ps}^{-1} (f_s = 0.10)$
ALEPH [46]	lepton-K-jet	$5.6 \text{ ps}^{-1} (f_s = 0.12 \pm 0.3)^*$
DELPHI [39]	lepton-jet	$4.2 \text{ ps}^{-1} (f_s = 0.10 \pm 0.3)^*$
DELPHI [47]	$D_s$ -lepton	$1.5 \text{ ps}^{-1}$
OPAL [41]	lepton-jet	$3.3 \text{ ps}^{-1} (f_s = 0.12 \pm 0.4)^*$
OPAL [41]	dilepton	$2.2 \text{ ps}^{-1} (f_s = 0.12 \pm 0.4)$

Table 9: Summary of  $\Delta m_s$  limits at LEP. Values quoted with a \* are preliminary results

illustration, figure 4 shows the limit on  $\Delta m_s$  from the dilepton analysis by ALEPH.

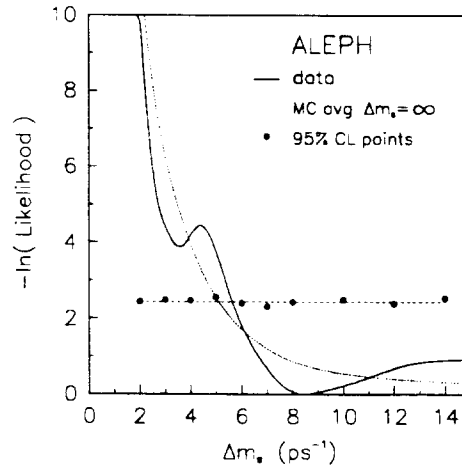


Figure 4: The negative log-likelihood fit for the data (relative to the point of maximum like-lihood), as a function of  $\Delta m_s$ . The points show the value of log-likelihood below which 95 % of Monte Carlo samples lie at a given value of  $\Delta m_s$ .

Using the LEP average value  $\tau_{B_s^0} = 1.591 \pm 0.106 \text{ ps}$  the limit  $\Delta m_s > 6.1 \text{ ps}^{-1}$  which corresponds to  $\Delta m_s/\Gamma_s > 9.7(\pm 0.6)$ . Using the LEP average value  $\Delta m_d = 0.456 \pm 0.020 \text{ ps}^{-1}$ , one obtains  $\Delta m_s/\Delta m_d > 13.4(\pm 0.6)$  which, using the theoretical estimation of  $(m_{B_s}, \eta_{B_s}, B_{B_s} f_{B_s}^2)/(m_{B_d}, \eta_{B_d}, B_{B_d} f_{B_d}^2)$  [44], yields :

$$\left| \frac{V_{ts}}{V_{td}} \right| > 3.1(\pm 0.25) \quad (10)$$

which is the best existing limit.



## 5 The measurement of $|V_{cb}|$

The magnitude of the  $CKM$  matrix element  $|V_{cb}|$  can be determined either from inclusive semileptonic  $B$  decays or from exclusive channels such as  $\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l$ . These two methods have both been exploited at LEP and at experiments running at the  $\Upsilon(4s)$ .

In the inclusive method  $|V_{cb}|$  is determined from the inclusive  $b$  hadrons semileptonic width  $\Gamma(B \rightarrow X\ell\nu)$  via the equation:

$$F_c|V_{cb}|^2 + F_u|V_{ub}|^2 = \frac{192\pi^3}{G_F^2 m^5} \Gamma(B \rightarrow X\ell\nu) \quad (11)$$

where  $F_c$  and  $F_u$  are coefficients which include phase space and  $QCD$  corrections. Although statistically not limited, the inclusive method suffers from large theoretical uncertainties of the order of 10 % due mainly to the unknown higher order corrections in the expansion for the semileptonic width in  $\alpha_s(m_b)$  [48].<sup>1</sup>

The determination of  $|V_{cb}|$  from exclusive decay such as  $\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l$  has less theoretical limitations compared to the inclusive method. In the framework of the heavy quark effective theory (HQET) [50], this decay mode can be expressed, to the leading order, in terms of only one form factor, the Isgur-Wise function. Although HQET cannot predict the shape of this function, for decays close to zero recoil (decays of maximum  $q^2$ )<sup>2</sup>, it is absolutely normalized up to corrections of order  $1/m_b^2$  [52]. This normalization provides a reliable determination of  $|V_{cb}|$ .

The strategy, commonly used [51], to extract  $|V_{cb}|$  from the decay  $\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l$ , is to fit its measured differential decay rate and to extrapolate it up to the point of maximum  $q^2$ :

$$\begin{aligned} \frac{d\Gamma}{d\omega} &= \frac{1}{\tau_{B^0}} \frac{dBr(\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l)}{d\omega} \\ &= G(\omega) \mathcal{F}^2(\omega) |V_{cb}|^2 \end{aligned} \quad (12)$$

where  $\omega = v_{B^0} \cdot v_{D^*} = (m_B^2 + m_{D^*}^2 - q^2)/2m_B m_{D^*}$ ,  $G(\omega)$  is a known phase space function and  $\mathcal{F}(\omega)$  is a universal form factor with unknown shape. At  $\omega = 1$  (maximum  $q^2$ )  $G(\omega) \approx 0$  and  $\mathcal{F}(\omega) \cdot |V_{cb}|$  is determined by extrapolation.

The first measurements of  $|V_{cb}|$  with this method were performed by ARGUS and CLEO experiments [53, 54]. At LEP, ALEPH used the same method and reported the first measurement of  $|V_{cb}|$  in [55]. ALEPH has reconstructed a sample of 410  $\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l$  candidates from which the differential decay rate  $d\Gamma(\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l)/d\omega$  was reconstructed. The  $\omega$  variable was reconstructed from the  $D^{*+}l^-$  system with a resolution of 14 % of the allowed range. Figure 5 shows the reconstructed  $\mathcal{F}(\omega) \cdot |V_{cb}|$  distribution with a fit superimposed using a linear  $\mathcal{F}(\omega)$  shape

<sup>1</sup>Some theorists [49] claim that the theoretical uncertainty does not exceed 5%

<sup>2</sup>The  $q^2$  is the mass squared of the virtual  $W$ , i.e. for the decay  $\overline{B}^0 \rightarrow D^{*+}l^-\overline{\nu}_l$ , the mass squared of the  $(l, \nu)$  pair.

with a slope  $a^2$ . The fit yields the following result:

$$\begin{aligned}\mathcal{F}(1) \cdot |V_{cb}| &= (3.14 \pm 0.23_{\text{stat}} \pm 0.25_{\text{syst}}) \times 10^{-2} \\ a^2 &= 0.39 \pm 0.21_{\text{stat}} \pm 0.12_{\text{syst}}\end{aligned}\quad (13)$$

The systematic error is mainly due to the error on the relative abundance of  $B_d^0$  in  $b$  hadronic events, the relative proportion of non resonant  $B^0$  decays and the fitting method.

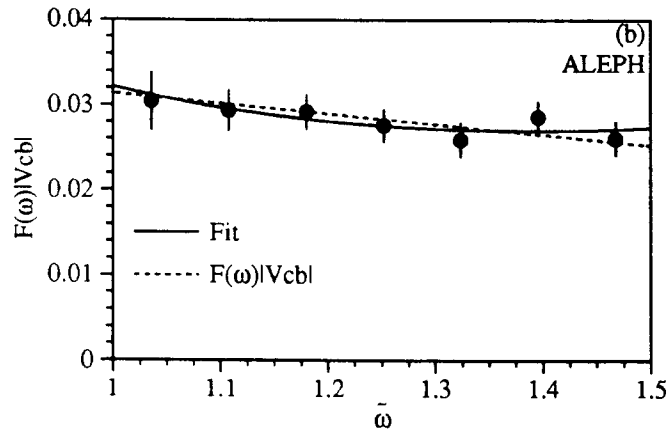


Figure 5: The product  $\mathcal{F}(\omega) \cdot |V_{cb}|$  as a function of  $\omega$ . The value of  $\mathcal{F}(\omega = 1) \cdot |V_{cb}|$  corresponds to the intercept of this curve.

This result is to be compared to the latest CLEO result [54] :

$$\begin{aligned}\mathcal{F}(1) \cdot |V_{cb}| &= (3.51 \pm 0.19_{\text{stat}} \pm 0.19_{\text{syst}}) \times 10^{-2} \\ a^2 &= 0.84 \pm 0.13_{\text{stat}} \pm 0.08_{\text{syst}}\end{aligned}\quad (14)$$

Using  $\mathcal{F}(1) = 0.91 \pm 0.04$  [56], the result for  $|V_{cb}|$  from ALEPH is:

$$|V_{cb}| = (3.45 \pm 0.25_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.15_{\text{theory}}) \times 10^{-2} \quad (15)$$

## 6 Conclusions

LEP has provided numerous interesting new results in  $B$  physics. Among these results :

- $R_b$  has been measured with a relative precision of  $< 1\%$  and showed a discrepancy of  $2.5 \sigma$  with respect to the standard model prediction. This is the only deviation observed from the standard model. It is yet to be understood and interpreted.

- $b$  hadron lifetimes have been measured with good precision. The hierarchy among  $b$  hadron lifetimes agrees with theoretical prediction although  $\tau_{\Lambda_b}/\tau_{B^0}$  is  $2\sigma$  lower than expected.
- $B_d^0 - \bar{B}_d^0$  time dependent oscillations have been measured for the first time at *LEP* and its oscillation frequency  $\Delta m_d$  measured with good precision. For  $B_s^0 - \bar{B}_s^0$  oscillations a direct limit  $\Delta m_s > 6.1 \text{ ps}^{-1}$  has been set for the first time.
- The *CKM* matrix element  $|V_{cb}|$  has been measured at LEP by ALEPH with a relative error of 10 % and it agrees with the values measured by ARGUS and CLEO.

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## References

- [1] D. Buskulic *et al.* (ALEPH collab.) *Z. Phys.* **C 62** (1994), 179.
- [2] D. Buskulic *et al.* (ALEPH collab.) *Phys. Lett.* **B 313** (1993), 549.
- [3] D. Buskulic *et al.* (ALEPH collab.) *Phys. Lett.* **B 313** (1993), 535.
- [4] DELPHI collaboration, *Measurement of the partial decay width  $R_b = \Gamma_b/\Gamma_{\text{had}}$  with the DELPHI detector at LEP*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0570.
- [5] B. Aveda *et al.* (L3 collab.) *Phys. Lett.* **B 261** (1991), 177.
- [6] O. Adriani *et al.* (L3 collab.) *Phys. Lett.* **B 307** (1993), 237.
- [7] R. Akers *et al.* (OPAL collab.) *Z. Phys.* **C 60** (1993), 199.
- [8] R. Akers *et al.* (OPAL collab.) *Z. Phys.* **C 65** (1995), 17.
- [9] H. Fritzsch and P. Minkowski, *Phys. Rep.* **73** (1981), 67.

- [10] Review of Particle Properties, L. Montanet *et al.*, Phys. Rev. **D 50** (1994).
- [11] I. Bigi, B. Block, M. Shifma, N. Uraltsev, A. Vainshtein, CERN - TH. 7132/94.
- [12] D. Buskulic *et al.* (ALEPH collab.) CERN-PPE/95-121 submitted to Phys. Lett. **B**.
- [13] P. Abreu *et al.* (DELPHI collab.) CERN-PPE/94-024 submitted to Z. Phys. **C**.
- [14] O. Adriani *et al.* (L3 collab.) Phys. Lett. **B 317** (1993), 474.
- [15] P.D. Acton *et al.* (Opal collab.) Z. Phys. **C 60** (1994), 217.
- [16] DELPHI collaboration, *Updated precise measurement of the average lifetime of B hadron*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0751.
- [17] ALEPH Collab., *Measurement of the  $\bar{B}^0$  and  $B^-$  Meson lifetime*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0412.
- [18] P. Abreu *et al.* (DELPHI collab.) CERN-PPE/95-060 submitted to Z. Phys. **C**.
- [19] R. Akers *et al.* (OPAL collab.) CERN-PPE/95-019 submitted to Z. Phys. **C**.
- [20] W. Adam *et al.* (DELPHI collab.) CERN-PPE/95-059 submitted to Z. Phys. **C**.
- [21] ALEPH Collab., *Improved Measurement of the  $B_s^0$  lifetime with  $D_s^- l^+$  combinations*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0402.
- [22] D. Buskulic *et al.* (ALEPH collab.) CERN-PPE/95-092 submitted to Z. Phys. **C**.
- [23] DELPHI Collab.,  *$B_s^0$  meson lifetime*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0559.
- [24] R. Akers *et al.* (OPAL collab.) CERN-PPE/95-020 submitted to Phys. Lett. **B**.
- [25] ALEPH Collab., *Update Measurement of the b Baryon lifetime*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0753.
- [26] DELPHI Collab., *Beauty-baryons production properties and lifetimes*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0564.
- [27] R. Akers *et al.* (OPAL collab.) CERN-PPE/95-051 submitted to Phys. Lett. **B**.
- [28] R. Akers *et al.* (OPAL collab.) CERN-PPE/95-090 submitted to Z. Phys. **C**.

- [29] C. Albajar *et al.* (UA1 collab.), *Phys. Lett. B* **186** (1987), 247.
- [30] H. Albrecht *et al.* (ARGUS Collab.), *Phys. Lett. B* **192** (1987), 245.
- [31] M. Artuso *et al.* (CLEO Collab.), *Phys. Rev. Lett.* **62** (1989), 2233.
- [32] R.W. Forty, *CP violation and  $B - \bar{B}$  mixing*, Proc. of the XXVII Int. Conf. on High Energy Phys., Glasgow, (IOP Publishing, 1995), 171.
- [33] D. Buskulic *et al.* (ALEPH collab.), *Z. Phys. C* **62** (1994), 179.  
D. Buskulic *et al.* (ALEPH collab.), Contributed paper to Lathuile and Moriond Winter conferences, 1994; ALEPH 94-036.
- [34] W. Abreu *et al.* (DELPHI collab.), *Z. Phys. C* **66** (1995), 323.
- [35] M. Acciarri *et al.* (L3 collab.), *Phys. Lett. B* **335** (1994), 542.
- [36] R. Akers *et al.* (OPAL collab.) *Z. Phys. C* **60** (1993), 199.
- [37] D. Buskulic *et al.* (ALEPH collab.) *Phys. Lett. B* **313** (1993), 498 ; D. Buskulic *et al.* (ALEPH collab.) *Phys. Lett. B* **322** (1994), 441.
- [38] ALEPH Collab., *Measurement of the  $B_d^0 \bar{B}_d^0$  oscillation frequency*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0409.
- [39] DELPHI Collab., *Improved measurement of the oscillation frequencies of  $B^0$  mesons*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0568.
- [40] OPAL Collab., *Update of the measurement of the  $B_d^0$  oscillation frequency using a jet charge technique*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0275.  
R. Akers *et al.* (OPAL collab.) *Phys. Lett. B* **336** (1994), 585.
- [41] R. Akers *et al.* (OPAL collab.) *Z. Phys. C* **66** (1995), 555.  
OPAL Collab., *A study of  $B$  meson oscillations using inclusive lepton events.*, contributed paper to the International Symposium on Lepton-Photon Interactions, Beijing, 10-15 August 1995, Ref. OPAL-PN196.
- [42] F. Abe *et al.* (CDF Collab.), *Phys. Rev. Lett.* **74** (1995), 2626.  
S. Abachi *et al.* (D0 Collab.), *Phys. Rev. Lett.* **74** (1995), 2632.
- [43] A.J Buras, M. Jamin and P.H. Wiesz, *Nucl. Phys. B* **347** (1990), 491.
- [44] A. Ali and D. London, *CP Violation and Flavour Mixing in the Standard Model* DESY 95-148, UdeM-GPP-TH-95-32, hep-ph/9508272.
- [45] D. Buskulic *et al.* (ALEPH collab.) *Phys. Lett. B* **356** (1995), 409.

- [46] ALEPH Collab., *Time dependent  $B_s^0$  mixing from lepton-kaon correlations with the ALEPH detector*, contributed paper to EPS-HEP 1995 conference, Brussels, 27th July-2nd August 1995, Ref. EPS0410.
- [47] DELPHI Collab., note for winter conferences, March 1995.
- [48] M. Neubert, Phys. Lett. **B 338** (1994), 84 ; Phys. Lett. **B 341** (1995), 367
- [49] M. Shifman.  $|V_{cb}|$  *from OPE sum rules for Heavy Flavor transitions*, Proc. of the XXVII Int. Conf. on High Energy Phys., Glasgow, (IOP Publishing, 1995), 1125.
- [50] For a review on HQET see M. Neubert, Phys. Rep. Volume **245**, Number **5 & 6** (1994), 259. and references therein.
- [51] M. Neubert, Phys. Lett. **B 264** (1991), 455.
- [52] M.E. Luke , Phys. Lett. **B 252** (1990), 447.
- [53] H. Albrecht *et al.* (ARGUS Collab.), Phys. Lett. **B 197** (1987), 452. D. Bortoletto *et al.* (CLEO Collab.), Phys. Rev. Lett. **63** (1989), 1667.  
R. Fulton *et al.*, (CLEO Collab.), Phys. Rev. D **43**, (1991), 651.  
H. Albrecht *et al.* (ARGUS Collab.), Phys. Lett. **B 275** (1992), 195.  
H. Albrecht *et al.* (ARGUS Collab.), Phys. Lett. **B 324** (1994), 249.  
H. Albrecht *et al.* (ARGUS Collab.), Z. Phys. **C 57**, (1993), 533.
- [54] B. Barish *et al.* (CLEO collab.), Phys. Rev. **D 51** (1995), 1014.
- [55] D. Buskulic *et al.* (ALEPH collab.) CERN-PPE/95-094 submitted to Phys. Lett. **B**.
- [56] M. Neubert. *Uncertainties on the determination of  $|V_{cb}|$*  CERN-TH/95-107.